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INFLUENCE OF TROPICAL CYCLONE BAAZ AND FANOOS ON PHYTOPLANKTON BLOOMS (CHLOROPHYLL-*A*) OVER BAY OF BENGAL: A SATELLITE BASED OBSERVATION

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ABSTRACT

Landfall of TC's (tropical cyclone) constitutes one of the most destructive natural disasters that leading terrific annual losses in lives and property. Although in ocean, cyclone wind causes local mixing which results in the inoculation of nutrients into the upper layer of the ocean and triggering phytoplankton bloom. This study investigates phytoplankton blooms subsequent the passage of TC in the BOB (Bay of Bengal) basin. The fluctuation of sea surface temperature (SST), storm surface winds, precipitation and chlorophyll (Chl-*a*) were supervised for two consecutive tropical cyclone, Baaz (28^{th} November to 2^{nd} December, 2005) and Fanoos (6^{th} -10^{th} December, 2005). In the study, combined data sets of SST from AMSR-E, rainfall from TMI, wind speed from QuikScat and ocean color product from SeaWiFS are used to analyze physical, biological and optical process before, during and after the cyclone. Results established that mean Chl-*a* inversely correlated with the SST ($r= -0.62$, $p<0.005$) and positively correlated with the average rainfall ($r=0.51$, $p<0.005$) and wind speed ($r=0.49$, $p<0.005$). Along track mean Chl-*a* concentrations after the cyclonic period increased from ~0.11 mg/m3 to 12.52 mg/m^3. Increase of Chl-*a* concentrations varies from 34.91% to 87.46% in near the shore water and 38.24% to 79.63% in central bay, over a region of ~81km^2 (a single pixel of Sea-WiFS data). 16days after, patches of phytoplankton boom decreased significantly with values at~0.056 to 4.23 mg/m3 and after 20days elevated level of Chl-a concentration almost returned back to the pre-cyclone levels.

KEYWORDS: BOB, Tropical Cyclones, SST, Remote Sensing and Phytoplankton Blooms

INTRODUCTION

The north Indian Ocean is inherently red zone for tropical cyclone (TC) and the development of cyclonic storms is accounts for about 13% of the global annual total number of tropical storms (Gray, 1968). The Ocean is consisting of the Arabian Sea to the west of the Indian subcontinent and the Bay of Bengal (BOB) to the east and which experiences an average 4 to 6 storms during the season between April and December, with peaks in May and November. The ratio of the frequency of TC over the Bay of Bengal and the Arabian Sea is 4:1 (Dube, 1997). Tropical cyclone is very destructive to land lives, damage of property and disrupting the natural ecology on the land surface. Conversely, in the ocean, it has a significant impact on phytoplankton bloom as well as marine ecology (Madhu, 2002; Maiana, 2008). In the tropics and subtropics region tropical cyclone or, typhoons plays an important role in nourishing the phytoplankton blooms (Guang and DanLing, 2007). The changes in upper ocean phytoplankton blooms is varies with a particular cyclone and it is depends on several parameters involving atmospheric and oceanic variables (Price, 1981; Dickey *et al*, 1998b). Baaz (28^{th} November to 2^{nd} December 2005) and Fanoos (6^{th} -10^{th} December 2005) are two consecutive tropical cyclones occurred in the BOB with the average speed of 84km/h and 85 km/h, respectively. Under the influence of an upper air

cyclonic circulation both the tropical cyclones was formed over the south Andaman Sea in BOB and moved in a westerly direction within the latitude extension of 10°N to 14°N. Due to large amount of cloud cover, heavy rainfall and rapid wind speed of cyclone, it is not possible to identify the potentials impact of cyclone on ocean biology by an in-situ measurement. Therefore, satellite based remotely sensed data are quite useful for continuous observation and synoptic view of the extensive ocean and it is being used in various ocean related study to retrieval of oceanic physical and biological properties (Wick and Gary, 2002; Moore, 2009; Gohin et al, 2011; Wernand, 2013). Simultaneously, GIS techniques are being utilized to estimate, analysis, mapping and visualization the satellite data. In the present study, cyclone induced high chlorophyll concentration features along the tracks was analyzed and estimated using the satellites observation on the ocean and results were also correlated with the different variables including SST, wind speed, wind pressure and rainfall.

MATERIALS AND METHODS

Study Area

Study was conducted in BOB, the largest inlet (surface area coverage 2,172,000 km²) in the world (Figure 1) surrounded by Bangladesh to the north, India and Sri Lanka to the west and Burma (Myanmar) and the Andaman and Nicobar Islands to the east. This is a cyclone-dominated part of the Indian Ocean (lies between latitudes 5° - 22° N and longitudes 80°- 90° E). Annually, an average of 7 % of the global cyclonic storm was reported from this region. A large number of rivers namely Mahanadi, Godavari, Krishna, and Kaveri on the west side and the Ganges and Brahmaputra from the north face linked with the BOB.

Formation and Movement of Baaz and Fanoos

Baaz and fanoos are two consecutive tropical cyclone formed over the BOB during post monsoon season in 2005. Cyclonic storm baaz over the Bay of Bengal during 28th November to 2nd December was a low-pressure system with constant convection in its centre instigated over south Andaman Sea on 27th November (10.5°N and 90.5°E). It intensified into a deep depression over east central BOB at 0600Z (11°N and 86°E) on 28th November and into a cyclonic storm named baaz at 2100Z (10.5°N and 88°E) on 28th November. The storm continued to move in a north-westerly direction with an average speed of 84km/hour (mean central pressure 998 mba). After, 99 hours of travel finally dissipated as a significant tropical cyclone over sea near or, north of Chennai. Just in 4days gap a deep depression was formed over west of the Andaman Islands (11°N and 89°E). It became cyclonic storm Fanoos at 0600Z on 7th December (11°N and 87.5°E). After 3days of travel (average 85km/hour) fanoos deteriorated into a deep depression at 000Z on 10th December prior to crossing coast north Tamilnadu near Vedaranyam (10.4°N and 79.85°E).

Sample Site Selection and Data Analysis

To explore the impact of tropical cyclone activities on the phytoplankton bloom analysis were included in two ways (i.e. remotely sensed satellite data analysis and second application of GIS to obtain the database). A grid area of 216*108 km^2 was randomly selected at 4 different places (A, B, C and D center point located at 10°54'59.98"N & 89°10'00.08''E, 10°54'59.98"N & 86°45'00.08''E, 10°24'59.98"N & 83°30'00.08''E, and 12°54'59.98"N & 82°45'00.08''E; respectively) along the tracks of tropical cyclones produced in IMD report (Figure 1). Sample sites were selected based on average wind speed and radius of maximum wind during the cyclone. These data were accumulated from the IMD (Indian Meteorological Department) website and later incorporated in a GIS database. Separate shape files (i. e. point, polygon and line) of the cyclone tracks and sample sites were generated and overlaid on satellite imageries for data visualization and information extraction. Along track and contiguous changes of phytoplankton bloom's were

measured before, during and after the cyclone and its statistical co-relation analysis was executed with the different characteristics of cyclonic storm (i.e. SST, rainfall, wind speed and wind pressure).

Data Collection Pre-Processing and Analysis

NASA's satellite based remote sensing observation was used in the study. Daily changes of sea surface temperature (SST) during the cyclone was observed from the remote sensing satellites Tropical Rainfall Measuring Mission Microwave Imager (TMI) (http://www.remss.com/missions/tmi) and Advanced Microwave Scanning Radiometer-Earth observing system (AMSR-E) (http://www.remss.com/missions/amsre) with spatial resolution of 9km. Daily rainfall information was extracted from the remote sensing observation of Tropical Rainfall Measuring Mission Microwave Imager (TMI) with a spatial resolution of 25km. We also used 8-day composite, 9 km resolution level-3 ocean colour product by NASA's SeaWifs (http://oceancolor.gsfc.nasa.gov/), which captured only a part of the chlorophyll *a* bloom patch because of the heavy cloud cover during the cyclones. The near-real-time measurements by Quick SCAT with a spatial and temporal resolution of 25km and 1day respectively (http://www.remss.com/missions/qscat), was used to calculate the wind speed, wind direction and radius of the eye points. Satellite data georeferencing, pre-processing and information extraction were performed in the remote sensing image analysis software namely ENVI and ERDAS imagine. Statistical analysis and graph preparation done in SPSS software (Version-21).

RESULTS AND DISCUSSIONS

With the advancement of ocean color remote sensing from satellite observation upper-ocean biological and physical response to buzz and fanoos has been observed and analyzed. Location of the SS (sample sites) along the tracks of tropical cyclones has been depicted in the figure 1, SS-1 was located in the eastern BOB, SS-2 was in the central Bay, SS-3 was also in the central bay but come near to the Tamilnadu cost and SS -4 was situated in western BOB and near the cost of north Chennai. Average wind speed during the cyclone in SS-1, 2, 3 and 4 were observed 8.70, 12.12, 11.84 and 11.33 m/s, respectively. Highest rainfall along the cyclonic track was recorded in SS-2 (average-1.64mm/hr) followed by SS-4 (average-1.51mm/hr), SS-3 (average-1.04mm/hr), and SS-1(average-0.55mm/hr). The SS-1, the starting point of both the cyclone, initial SST was observed in surface water >28°C and during the cyclone SST was decreased 0.44°C and 0.46°C along the track of baaz and fanoos, respectively [Figure 2(a),(b),(e) & (f)]. The highest fluctuation was observed at SS-4 (0.56°C, cyclone baaz passed on the region, Figure 2c & d.) in near shore water and lowest differences were observed at SS-2 [0.36°C and 0.38°C during baaz and fanoos, respectively, Figure 2(c), (d), (g) & (h)] and SS-3 [0.36°C, cyclone fanoos passed on the region, Figure 2(g) & (h)] in the central bay. Cyclone baaz and fanoos had higher translation speed at SS -2 (3.13 m/s^{-1}) and SS- 3 (3.21 m/s^{-1}) in compare to SS-4 (2.54 m/s^{-1}) and 1 (2.73 m/s^{-1}). The physical effects of cyclones such as decrease in SST depends on the ocean mixed layer, transit speed and the vertical motion associated with upwelling and downwelling cycles during the cyclone, have been well described in the previous studies (Price, 1981; Shay et al, 1989). Before baaz and fanoos, chl-a concentration at the sea surface along the cyclone track was low at ~0.11-0.29mg/m^3 (mean ± sd= 0.17±0.03), ~0.19-0.58mg/m^3 (mean ± sd= 0.33±0.09), ~0.22-0.60mg/m^3 (mean ± sd= 0.38±0.07) and ~0.18-0.51mg/m^3 (mean ± sd= 0.31±0.08) in the SS-1, 2, 3 and 4; respectively. 8days after the cyclones, enhanced Chl-a concentration was observed along the tracks and notable patch of high chl-a concentration was observed at the SS -4, SS-2 and SS-3 [Figure 3(d)]. Due to thick cloud coverage over the sample sites-1, 2 and 3, very few patches of Chl-a data were appeared in the Sea-WiFS imageries (8days composite data, Figure 3). Along track Chl-*a* concentrations after the cyclonic period increased from 0.16-0.39mg/m^3 (mean ± sd= 0.27±0.07), 0.21-8.35mg/m^3 (mean ± sd= 1.03±1.15),

0.25-1.25mg/m^3 (mean ± sd= 0.61±0.26) and 0.41-12.52mg/m^3 (mean ± sd= 1.13±1.48) in the SS-1, 2, 3 and 4; respectively. Total Chl-a concentration increased varies from 34.91% to 87.46% in near shore water and 38.24% to 79.63% in the central bay, over a region of ~81km^2 (a single pixel of Sea-WiFS data). Number of pixels having Chl-a concentration ≥0.5 was significantly increased after the cyclone (Figure 4). The lifted Chl-a region was found coincides with the location of the cyclone eye point and the area with strong wind intensity (Figure 3 & Figure 5). A significant inverse relationship was established between chl-a concentration and SST ($r= -0.62$, $p<0.005$). On the other hand, chl-a concentration was positively correlated with rainfall ($r=0.51$, $p<0.005$) and wind speed ($r=0.49$, $p<0.005$). 16days after, patches of phytoplankton boom was still observed but, Chl-a magnitude decreased significantly with values at ~0.056 to 4.23 mg/m3. After the cyclonic period, SST slowly increased at all the sample sites but it was observed still below the pre cyclone SST at the sample site- 4 (pre-cyclone- 27.9°C, during- 27.34°C and post-cyclone-27.58°C) and 2 (pre-cyclone- 28.18°C, during- 27.81°C and post-cyclone-27.93°C). It may be due to extensive and heavy rainfall after the cyclone at SS-4 (average-0.92mm/hr) and 2 (average-1.32mm/hr).The phytoplankton bloom also decreased quickly, and 20days after the Chl-a concentration level almost returned back to the pre-cyclone levels (Figure 6). Similarly, Babin et al. (2004) investigated thirteen hurricanes passage through a region of the subtropical North Atlantic and result showed chl-a increases ranging from 5% to 91% in the tracks of these hurricanes, and elevated level of Chl-a lasted 2–3 weeks returning to pre-hurricane concentrations.

Study showed that tropical cyclone plays a significant role in SST cooling and rising of phytoplankton bloom in the BOB region. Satellite based remote sensing observation delivered a significant result that surface chlorophyll concentration increases after the TCs, that increases is larger on the tracks of TCs and elevated level of Chl-a lasted up to two weeks after the cyclone. Monitoring of such ocean event using satellite data would be useful for guiding the fishermans to identify the potential fishing zones (PFZs) over the post cyclonic region in BOB as well as in entire ocean.

CONCLUSIONS

Study showed that tropical cyclone plays a significant role in SST cooling and rising of phytoplankton bloom in the BOB region. Satellite based remote sensing observation delivered a significant result that surface chlorophyll concentration increases after the TCs, that increases is larger on the tracks of TCs and elevated level of Chl-a lasted up to two weeks after the cyclone. Monitoring of such ocean event using satellite data would be useful for guiding the fishermans to identify the potential fishing zones (PFZs) over the post cyclonic region in BOB as well as in entire ocean.

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CONFLICT OF INTEREST

The author declares that there is no conflict of interest.

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APPENDICES

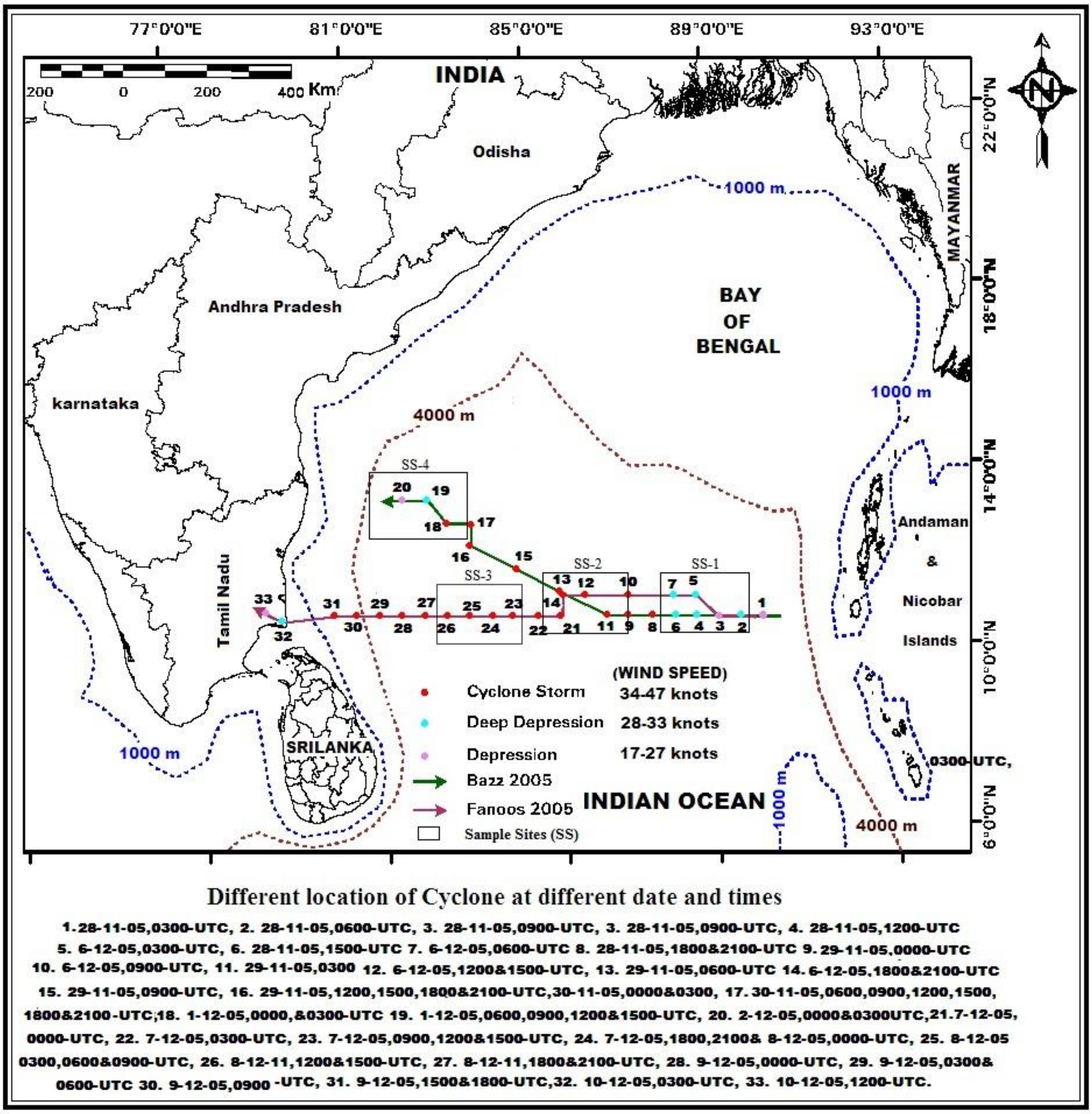

Figure-1

Location map of the study area shows the tracks of tropical cyclones Baaz (28th November to 2nd December, 2005) and Fanoos (6th December to12th December, 2005) in green and purple color, respectively. Cyclone eye points are marked along the tracks and wind speed was categorized by different color. Boxes in black line are indicating the location of sample sites has been used in the study.

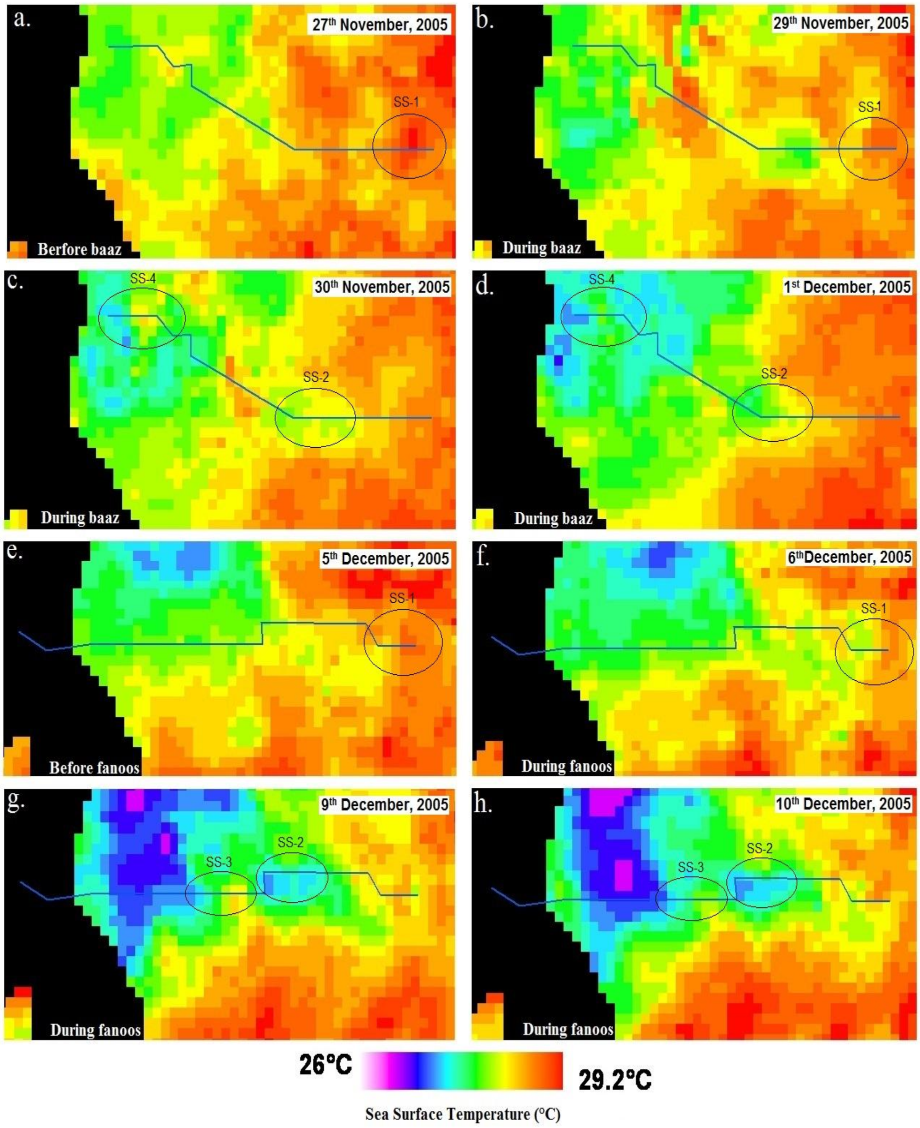

Figure 2: Timely Evolution of the SST (AMSR-E) Along the Track before and During the Tropical Cyclones Baaz and Fanoos

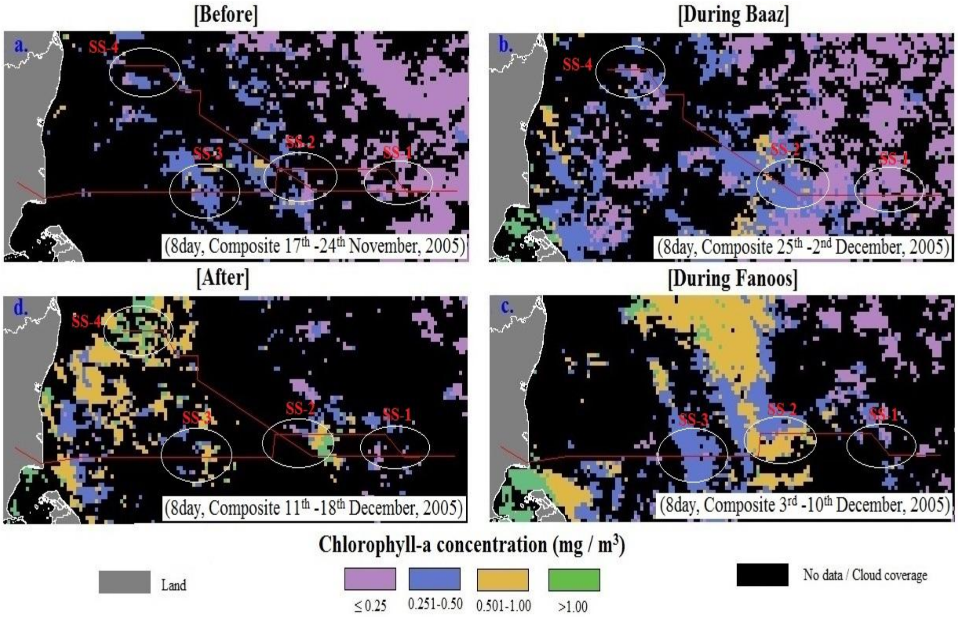

Figure 3: Timely Evolution of the Chl-A (8day Composite Sea-Wifs Data) along the Track before, During and after the Tropical Cyclones Baaz and Fanoos

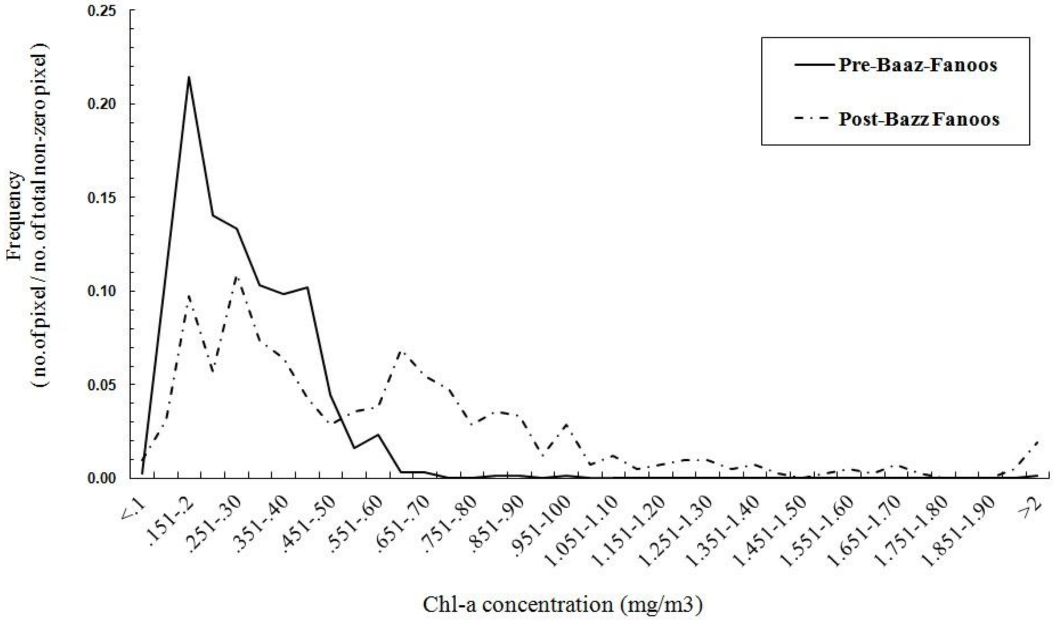

Figure 4: Frequency Estimation of Non-Zero Pixel of Chl-A Concentration Pre and Post Period of Baaz and Fanoos. Black Solid Line Represents the Status of Chl-A Pixel before the Cyclone and Black Dotted Line Represents the Status of Chl-A Pixel after the Cyclone

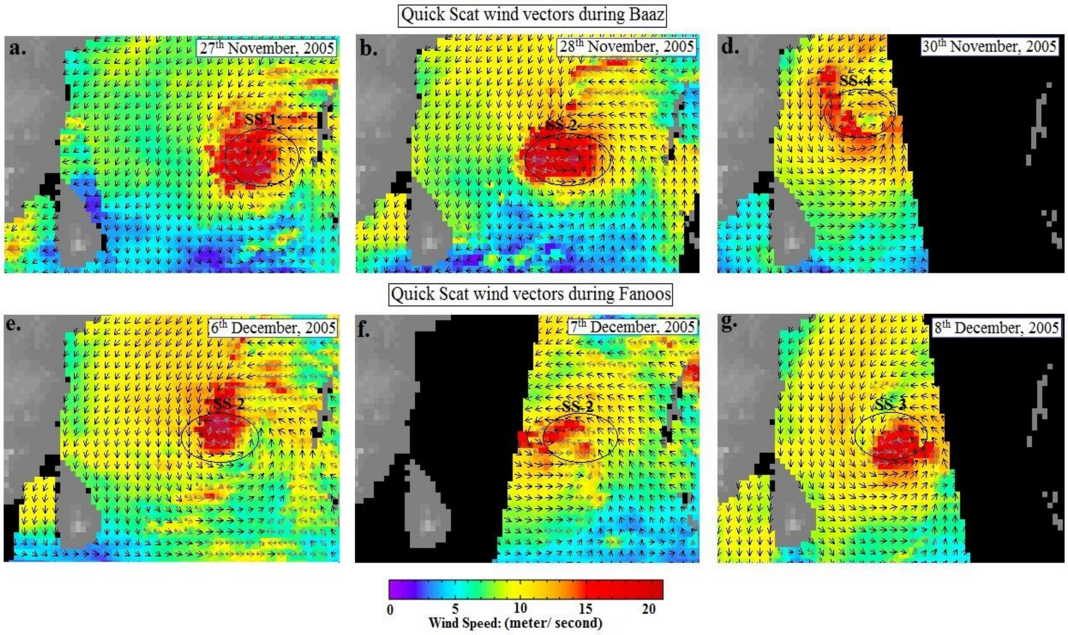

Figure 5: Spatio-Temporal Movement and Direction of Wind Vector (Quick Scat Data) Along the Track of Tropical Cyclones Baaz and Fanoos

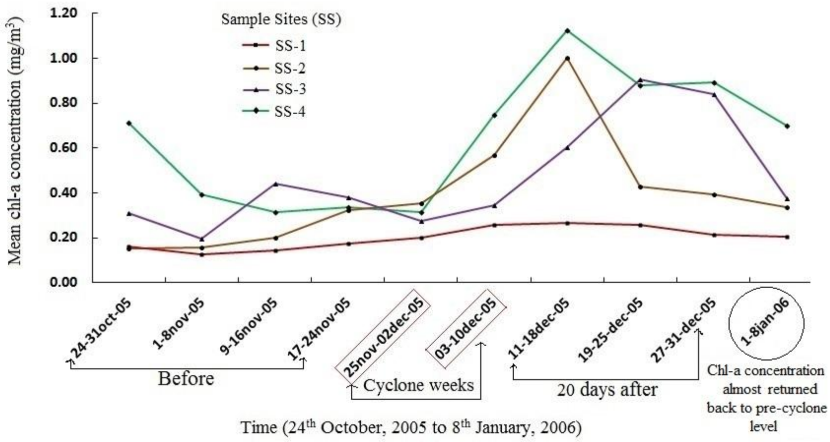

Figure 6: Temporal Response of Chlorophyll-A Concentration in the Sample Sites (SS) -1, 2, 3 and 4 before, During and after the Cyclonic Activities